Study of Maintenance Optimization and Maintenance Quantification in Nuclear Power Plants

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論文内容要旨

Since the 1970's maintenance in industrial plants has become more and more important. This is because industrial plants began growing larger rapidly. Problems, failures and accidents in these large plants may have very big impact on the owner, society and the environment. Only industrial plants that are well designed, constructed, operated and maintained can assure plant safety, economic efficiency, and high performance. Maintenance is very important and should be on the same footing with design, construction and operation. The US nuclear power industry since 1980 is a good example. Since 1980 the US nuclear plants have placed great emphasis on improving maintenance and, as a result, the plants are now performing at a very high level of safety and availability.

Up to now, Japan has largely emphasized design, construction and operation rather than maintenance in their nuclear plants. This is because maintenance was largely field or site oriented and experience based. There was little or no interest in developing the foundations of maintenance activities in a systematic way and as technical or academic discipline. This is in contrast to design, construction, and operation where a lot of technical knowledge and experience was assembled, then coupled with scientific techniques and methods, and organized into technical disciplines that could be widely taught, shared and applied.

However, recently the situation is shifting. A lot of technical experience and knowledge has also been accumulating in the maintenance area for Japanese nuclear power plants. So it is an appropriate time to utilize that information to develop fundamental principles applicable to maintenance. We can then lay down the foundation, couple these with scientific techniques and methods, and define a structured discipline of maintenance science or engineering.

This study, with the background described above, develops a systematic, quantitative evaluation method of maintenance for nuclear power plants by introducing the scientific approach and also reveals a method to search an optimum maintenance plan to be obtained by maximizing nuclear safety and economic efficiency simultaneously and balancing them. The summary of the study is shown below.

Chapter 1 describes an overview of this study.

In Chapter 2, the historical change in maintenance management methods in the industry are surveyed. The results of the survey showed it is necessary to develop a methodology of describing maintenance by taking the scientific and quantitative approach because there is no methodology in the world which incorporates such approach into. Using the result of the survey, the problems to solve in developing the methodology is identified and the approach to address the problems is developed.

In Chapter 3, discusses the maintenance fundamentals including the laws governing maintenance and their formulation. These laws are formulated by analyzing the fundamental structure of maintenance systematically, and by applying the scientific approach to maintenance. The structure of maintenance consists of plant system and human system, and maintenance activities between the two. The plant system has a nature of losing its function due to aging degradations with time during operation. The human system has a nature of restoring the function by maintenance work or activities. Maintenance activity forms a cycle of PDCA, called "maintenance cycle", which means "plan" "do" "check" and "act". These activities are developed between the two systems to maintain plant function. Based on this discussion and understanding, a methodology of quantifying and optimizing maintenance in nuclear power plants is proposed.

In addition, four key parameters are considered important from the viewpoint of maintenance: maintenance importance, maintenance level, safety (reliability) level and production reliability level. These parameters are defined and incorporated into the optimization method. Maintenance importance identifies important plant components from the viewpoint of plant safety and economic efficiency. Maintenance level is a semi-quantitative measure of the level of component condition after actual maintenance work. This is a new concept in the field of maintenance. This parameter is used to evaluate the plant safety level and production reliability level to be expected in the subsequent plant operation after actual maintenance work. The plant safety and production reliability level are evaluated by using component failure rates which are produced from the existing ones based on the maintenance level and are applicable to the evaluation of component conditions after actual maintenance work. The introduction of this parameter enables evaluating not only the condition of each component, but also the plant safety level and production reliability level of total plant system.

In Chapter 4, computer simulation analysis is carried out by applying the quantitative evaluation method described in Chapter 3 to maintenance planning for a couple of systems of a BWR-5 nuclear power plant. The analysis is conducted to search a best maintenance plan including components as preventive maintenance object, maintenance tasks for them and timing of implementation of the tasks from the viewpoint of nuclear safety and economic efficiency. The result proves that the proposed method could generate an optimum maintenance plan. However, to be fully useful this method needs information, such as the quantitative relation between maintenance tasks for each component and its resultant failure rate, and the quantitative relation between the failure rate of a component and the performance of the maintenance work team done on the component. Furthermore, the data including time, manpower, cost required for restoration after component failure is required. So it is necessary to build a database including the above data.

In Chapter 5, computer simulation analysis is also carried out for the planning of several maintenance works in a couple of systems during a BWR-5 plant outage in which a lot of maintenance work were concentrated, and many strict restrictions such as the technical specifications for nuclear facilities, physical plant site conditions etc. were imposed.

The analysis is conducted to search a best maintenance work plan including maintenance work schedule, man loading plan and cost for the maintenance work from the viewpoint of economic efficiency on condition that it complies with all the restrictions. As a result, the method proved that it could generate an optimum maintenance work plan. However, this method needs information such as manpower (man-days) for each maintenance task, number of workers, worker's unit price and so on. So it is necessary to build a database including the above data.

Chapter 6, based on the discussions in Chapter 3 to 5, defines a relation between maintenance optimization and maintenance performance targets, and a relation between maintenance performance targets and parameters relating to maintenance. Then Chapter 6 discusses the use of the performance indicators to evaluate maintenance effectiveness. Evaluating maintenance effectiveness is best done with actual plant data. Therefore, this study proposes performance indicators with a clear relation to maintenance performance targets, and that can be used to quantitatively evaluate maintenance effectiveness using actual plant data. These performance indicators show us the direction of improving the current maintenance program or practices, and lead us on the path to optimum maintenance. For instance, they can provide us with the answers to the questions such as: "What is the problem in the current maintenance program?" "What is the problem cause? "What are the countermeasures or corrective actions?"

Chapter 7 describes the conclusions of this study.

Looking back on the study above, the author keenly feels that it is very important and essential to establish an evaluation method for optimizing maintenance which is quantitative, and can be applied universally and generally. Technology or technical knowledge changes with the times; advanced or new technologies will appear. This will happen, not only in the area of maintenance, but also in the other areas. However, principles, basic laws or basic concepts, which have a high universality or generality, will not change. Such basic principles always will show us an appropriate direction; we will still know how to proceed even as technology changes or new technology develops.

Therefore, in this sense, academic foundations are essential also in the area of maintenance. First of all, we need an academic foundation in science, which handles concepts or theories, including the basic laws and equations governing maintenance and can describe maintenance by utilizing the existing sciences. This is academic foundation which is called "maintenance science" here. Maintenance science could be roughly divided into two separate fields. The first one is the "maintenance science and engineering" which aims at optimizing maintenance practices from the viewpoint of natural science. Another one is "maintenance sociology" which aims at optimizing maintenance practices mainly from the viewpoint of sociological science and humanities in order to obtain public understanding or acceptance. Second, we need an academic foundation in engineering and technology and also need an academic foundation in sociology. These two foundations can be assumed as the academic disciplines positioned on maintenance science, and can be applied to maintenance by utilizing the existing engineering and sociology. These are called "maintenance engineering" and "maintenance sociology" here, respectively. Finally, we have a foundation of "codes and standards" for maintenance positioned on the academic foundations or disciplines described above, and can be applied to actual maintenance plan and field work for maintenance. By making good use of all these foundations, optimum or best maintenance plan could be produced under given conditions, so the author believes that it is essential to establish such academic system or foundation for maintenance to optimize maintenance plan or maintenance-related activities.

The structure of the academic foundation explained above is shown in Fig.1.

In summary, over recent years, industrial plants or facilities have been getting larger and more complex and the

number has been increasing. This requires investing a huge amount of physical and human resources. So it is necessary and urgent to eliminate wasting any portion of these resources and changing the world and global environment of the better. This can be done by introducing the scientific and quantitative approach in the area of maintenance.

Through this study, the author shows the concept and methodology of maintenance optimization by introducing a scientific and quantitative approach into maintenance. However, this is only one example of the methodology of quantifying and optimizing maintenance. Therefore, it is necessary to continue to improve or refine the proposed methodology in this study, challenge this methodology to assure it is correct, and to perhaps create other methodologies. The author hopes to continue addressing the establishment of maintenance science, engineering and technologies.

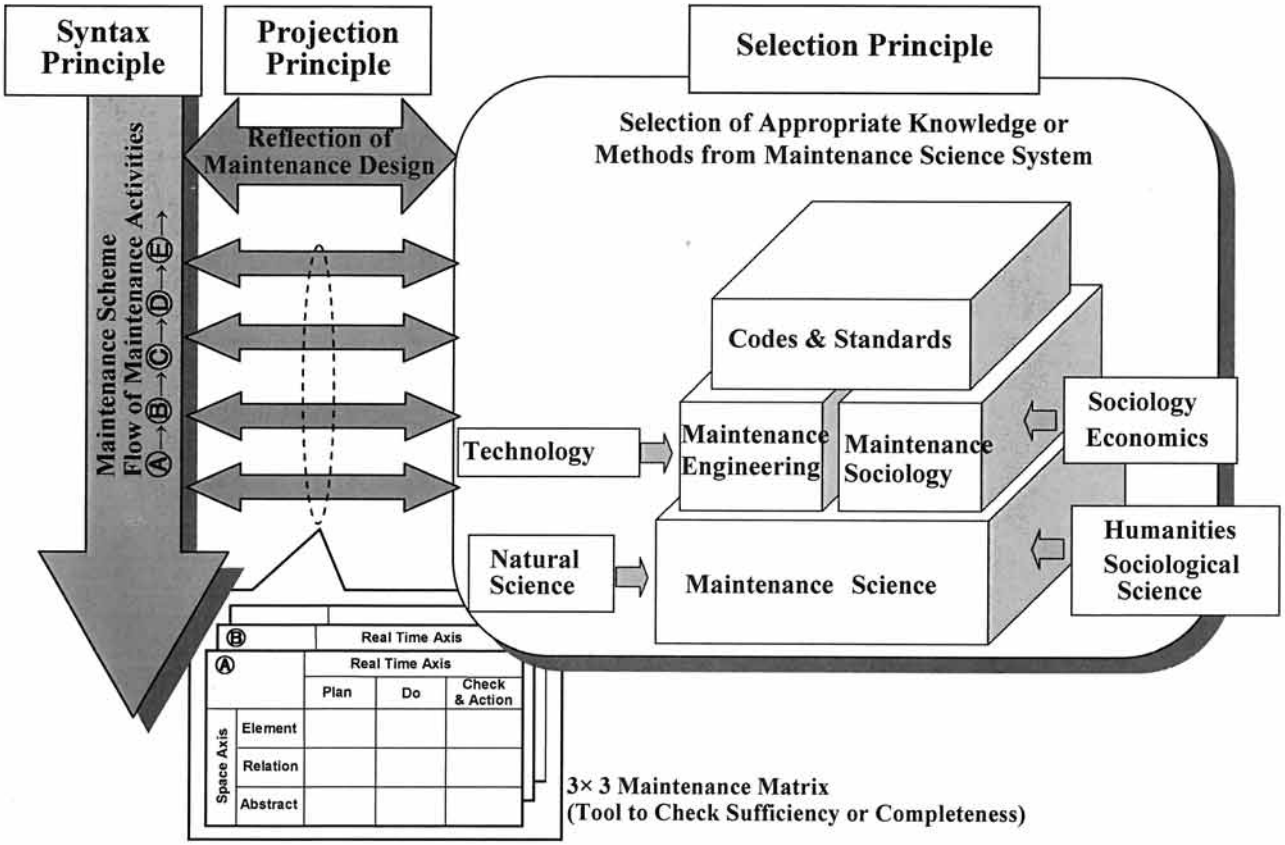

Fig.1 Scope of Maintenance Science and Technology